

Strategic Space Launch Concept and Technology Roadmaps to Develop Visionary Spaceports

FOR THE
50th International Astronautical Congress

Carey M. McCleskey
Technical Manager, Advanced Projects
NASA John F. Kennedy Space Center
Florida, U.S.A.

ABSTRACT

This paper presents a structured approach for developing strategic spaceport concepts and technologies within a larger space launch context. The approach centers on defining leapfrog “spacelift” affordability requirements (for instance, \$400/kg cost at daily flight rates). The approach assumes this capability is needed to satisfy visionary commercial markets, such as space solar power and public space travel, as well as human exploration enterprises. The methodology includes deriving a strategic space launch affordability allocation among major flight and ground cost elements. The paper describes how specific ground system functional cost elements are then distributed among eleven possible spaceport functional areas. Once the spaceport functions have been allocated as cost objectives, specific space launch concepts (both flight and ground systems) can then be analyzed. The paper further details a technology prioritization method with three strategic assessments: (1) an assessment of the operational or “fielded” benefit based on prioritized and measurable design criteria; (2) a programmatic assessment of the research and technology development phase; and (3) a programmatic assessment of the operational system acquisition,

also partitioned into three levels of investment risk. Finally, the paper describes how synthesizing the result leads to a strategic spaceport concept and technology portfolio with three development scenarios available for executive decision-makers to construct spaceport technology investment plans.

INTRODUCTION

Any serious discussion of the development of space transportation and commerce requires an understanding of the role of the “spaceport.” We can start by comparing the definition of the word “port”, as applied in the past for terrestrial applications, to the spaceborne application (see Figure 2). The *World Book* encyclopedia, for example, describes the main purpose of a port as “a place where ships and boats load and unload passengers and cargoes.”¹



Pat Rawlings/SAIC

FIGURE 1—Spaceports, a vital architectural element of a new age in spaceborne commerce. (*Artwork appearing in this paper commissioned by the Vision Spaceport partnership*)

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LEADING SEAPORTS OF THE U.S.

Total Volume of Foreign Trade (Metric Tons)*

(1) Houston-TX	92.3 Million Metric Tons
(5) NYC/New Jersey	50.8 Million Metric Tons
(9) Long Beach-CA	32.7 Million Metric Tons

*Source: U.S. Bureau of Census, "U.S. Waterborne Exports & General Imports, Annual 1997" (Issued July 1998)



enco

LEADING AIRPORTS OF THE WORLD

Total Volume of Cargo (Metric Tons)†

(1) Memphis-USA	2.4 Million Metric Tons
(4) Hong Kong	1.7 Million Metric Tons
(7) Frankfurt-GER	1.5 Million Metric Tons
(14) Amsterdam-NL	1.2 Million Metric Tons

†Source Airports Council International-ACI, On-line Traffic Data: (<http://www.airports.org/traffic/index.html>); Prelim., 18 Mar 99



Channel Express

LEADING SPACEPORTS OF THE WORLD

Total Cargo Mass Loaded & Unloaded (Metric Tons)‡

Cape Can./KSC-USA	~200 Metric Tons
Baikunur-KHA	?
Korou-FrG	?

‡Source No known international trade sources that publish worldwide spaceborne cargo traffic from spaceports



NASA Photo

FIGURE 2—Comparison of Worldwide Cargo Ports by Transportation Mode (*parenthetical numbers are rankings*)

A thriving, bustling seaport, then, could be described as having the buildings, facilities and equipment for receiving, storing and shipping goods, as well as loading and unloading passengers. Seaport facilities might include wharves, warehouses, tugs, and ferries. Technologies found in such facility functions may include bulk handling systems, ship loaders, conveyor systems, intelligent storage and retrieval systems and advanced process control. In addition, there are often connections to other modes of transportation including highways, railways, and airways.

Airports also have the means to perform basic transportation functions. Large, successful and thriving airports have achieved performance levels

of millions of metric tons of cargo traffic annually and tens of millions of passengers transported per annum.²

The development of commercial spaceports is still in its relative infancy. While it is entirely appropriate to begin examining the performance of today's space launch ranges and complexes, tracking actual spacelift performance—from a *spaceport perspective*—remains fertile and uncharted territory.³ For instance, tracking the amount of cargo mass loaded and unloaded from worldwide launch sites per annum, has not been uncovered.

It is also entirely appropriate to begin mapping various technological pathways that may enable commercially viable spaceport architectures

required for space development and growth. Spaceport concepts and technologies, in fact, is the subject of this paper, and the research and technology (R&T) focus at NASA's John F. Kennedy Space Center, USA.

SPACEPORT TECHNOLOGY CENTER (STC)

Recently, NASA's Kennedy Space Center (KSC) unveiled its *Spaceport Technology Center* initiative. With several important spaceport facility functions as its pillars (launch, landing and recovery, and payload processing), the Center is pursuing a set of Spaceport Technology Development Initiatives, or STDI's (see Figure 3).

EXPLORING SPACEPORT TECHNOLOGIES

Supporting the Spaceport Technology Center initiative is a small team of government, industry and academia experts. This Spaceport Synergy Team⁴ is currently conducting exploratory spaceport concept and technology research in connection with NASA's recently initiated Space Solar Power (SSP) activity.⁵ The SSP Concept Definition Study, conducted by NASA in 1998, began examining transportation system requirements for deploying massive space platforms that collect and transmit large amounts of solar power from space (hundreds of megawatts to gigawatt-class).⁶ The ambitious spacelift objective of the SSP concept provides an excellent framework to begin examining challenges that spaceport architects will face in the future.

For example, the study found that one configuration (see Fig. 4), referred to as the *Sun Tower*⁷, would require hundreds of flights to fully deploy. Further, it was assumed that if the SSP architecture were to be an economically viable energy source, a very high number of flights per year sustained for decades would be required.⁸ Thus, high performance spaceports become an

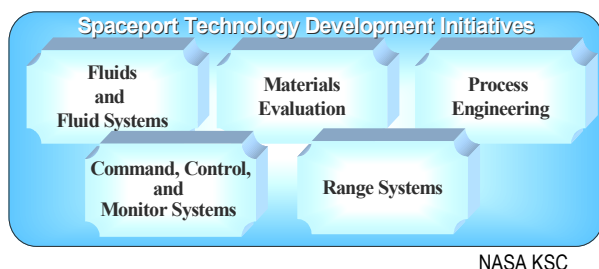


FIGURE 3—Spaceport Technology Center STDIs



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FIGURE 4: Space Solar Power, *Sun Tower*

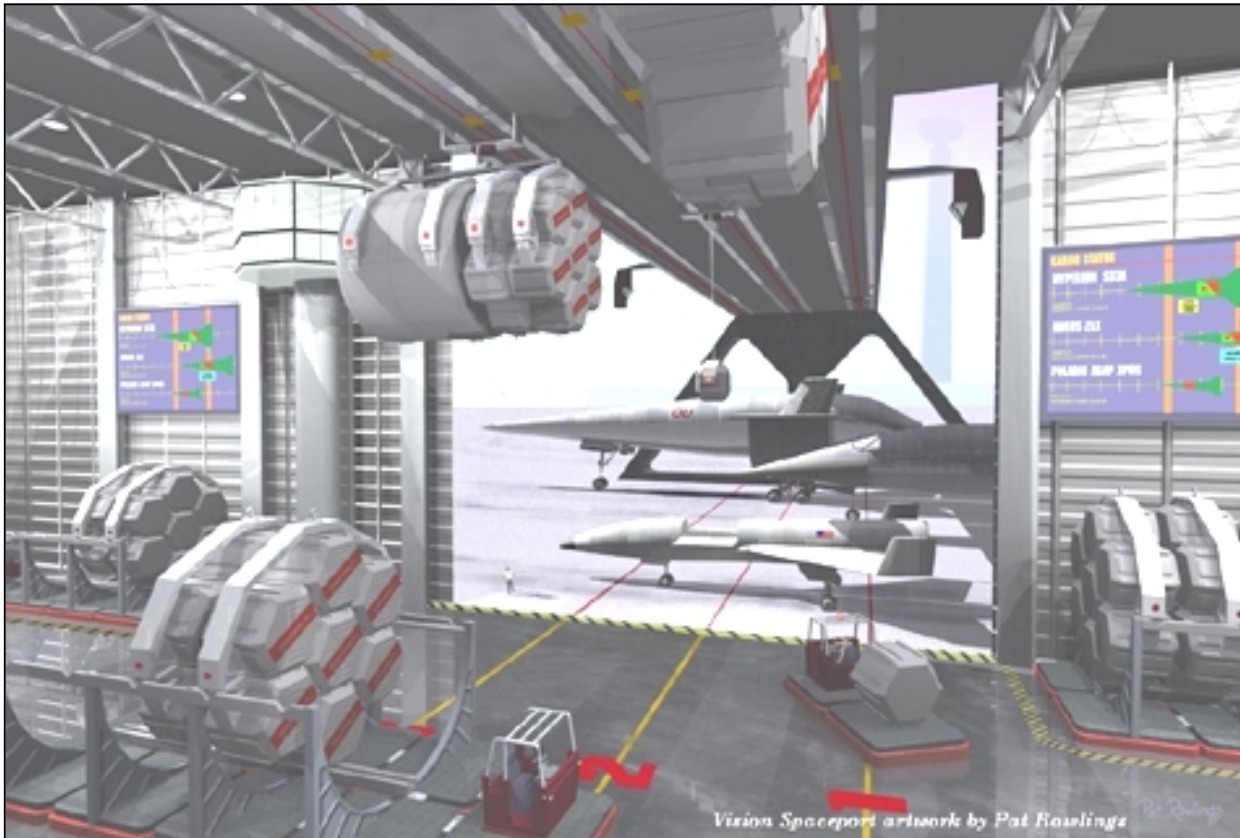
enabling architectural element in such an enterprise.

Another enterprise that is gaining interest and momentum is public space travel.⁹ While the SSP enterprise requires heavy cargo spacelift, public space travel brings new space transportation challenges of safety and passenger support capabilities. Which space transportation architectures (both flight and ground systems) offer the most promise for opening-up new space industries, such as space solar power and public space travel? The interactions between flight and ground systems are incredibly complex today, system concept choices are many, and technology options abound. Where to begin?

UNDERSTANDING GENERIC SPACEPORT FUNCTIONS

Key to the advancement of spaceport performance (safety, cost and throughput) is a comprehensive understanding of spaceport functions. Return for a moment to the seaport/airport analogies. Seaports interact with many different ships through common wharves and docks. Similarly, airports interact with many different types of airliners through a series of common concourses and gates. Today's launch complexes—even the newer and more innovative concepts—interact in a highly customized manner with highly customized launch pads. Most require specific servicing of commodities, complex and unique electrical services and a variety of command, control and communication protocols.

The launch facility element just described is, however, only one basic functional element of a spaceport. If spaceports are to become viable, self-sustaining entities that experience healthy growth



Pat Rawlings/SAIC

FIGURE 5—Offline Cargo Processing is an example of a *generic spaceport function*, and one that may be handled very differently in the future.

over time, a comprehensive understanding of all the functional elements of a spaceport is needed.

Once a generic set of possible spaceport functions are identified, then the process of improving spaceport performance becomes more organized.

Generic Spaceport Functions The Spaceport Synergy Team has previously identified a set of possible generic spaceport functions.¹⁰ Functions encountered at a generic operational spaceport depend primarily on the flight system needs. Some functions and subfunctions can be “designed-out” of the architecture. This, in fact, was one of the prime motivations in building the catalog of functions. Top-level functions are defined below:

Direct Spaceport Functions

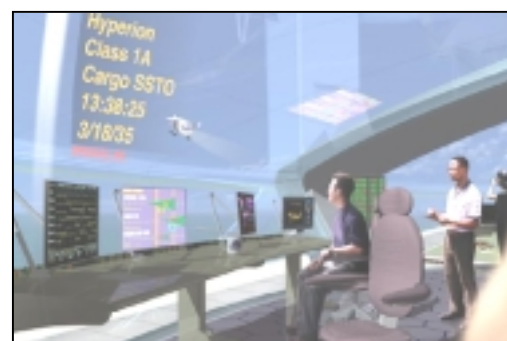
1. Off-line Cargo & Passenger Services (Fig. 5)
2. Traffic & Flight Control (Fig. 6)
3. Launch
4. Landing and Recovery

Optional Spaceport Functions (Concept-dependent)

5. Vehicle Turnaround Facility functions
6. Vehicle Assembly and Integration

Indirect Spaceport Functions

7. Vehicle Depot Maintenance
8. Spaceport Support Infrastructure
9. Concept-Unique Logistics
10. Transportation System Planning and Management
11. Connecting Community Infrastructure and Support Services



Pat Rawlings/SAIC

FIGURE 6—*Traffic & Flight Control* is another generic spaceport function. Current command, control and monitoring systems, with their firing rooms and range control centers, may evolve to airport-like traffic control towers as system maturity and demonstrated system reliability improve.

Spaceport Functional Performance Each generic spaceport function, as listed above, carries with it elements of cost, safety and throughput performance. Each generic function will need to acquire facilities and equipment. Additionally, they will need to be installed, certified for use, maintained and operated. Some functions may require new technologies to leap into new levels of performance. A spaceport can come into existence without acquiring some functions if those capabilities already exist. However, it must be remembered that the level of safety, cost and throughput performance is tightly coupled to the needs of the flight system. Therefore, spaceport functional performance will be tightly coupled to the types of flight system architectures associated with the spaceport design.

Benchmarking Spaceport Performance Possessing a generic functional description of a spaceport enables a structured and comprehensive understanding of the current state of spaceport performance. For instance, *benchmarking* labor levels associated with a spaceport function, or fixed operations and maintenance costs and cycle times that make up flight rate are greatly needed.

Spaceport Modeling Assuming the availability of

benchmarking data, analytical models can be constructed around the generic functions. These models can be used to identify functions needed for various space transportation system concepts. Projections could also be made of the effects of system reliability (flight and ground) on specific spaceport functions such as logistics, as well as overall spaceport functional performance, such as elevated labor levels, increased cycle time, etc.

Technology Prioritization & Planning Finally, technology planning can focus on “closing the gap” between the current state of spaceport functional performance and desired functional performance. The Spaceport Technology Center initiative, for example, currently focuses on three spaceport functional “pillars” and plans on “closing the gap” with several Spaceport Technology Development Initiatives (STDIs). Over time, as more and more information is gathered and analytical tools begin yielding needed answers, the emphasis may shift amongst various spaceport functions and new STDIs will arise. Regardless, the general Spaceport Technology Center approach is intended to provide a strategic, structured approach to improve the world’s space launch capabilities.

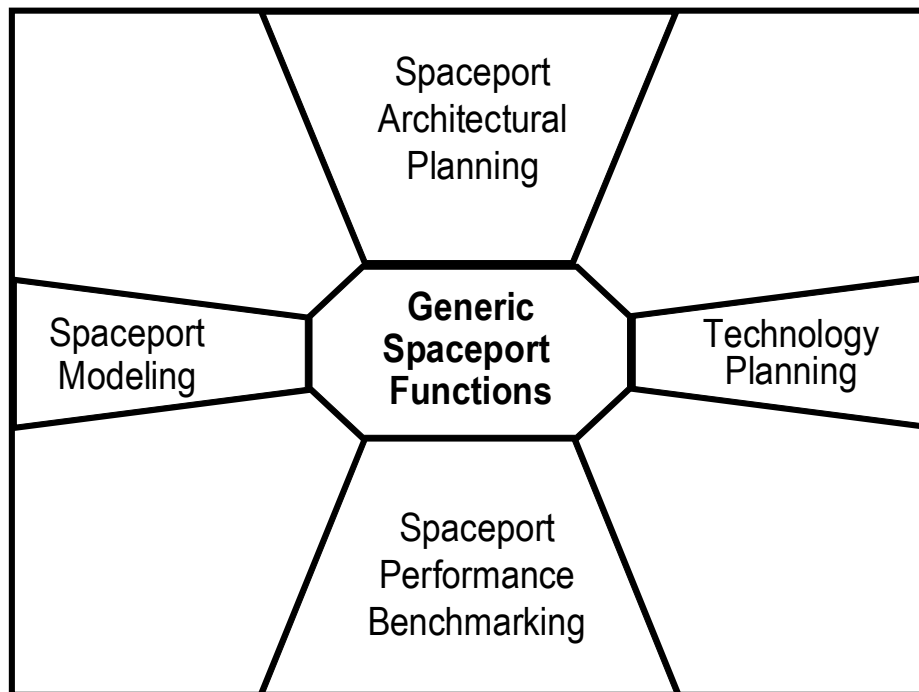


FIGURE 7—Understanding of generic spaceport functions and spaceport functional performance is central to advanced space transportation development

Space Solar Power Strategic Technology Approach — Level I

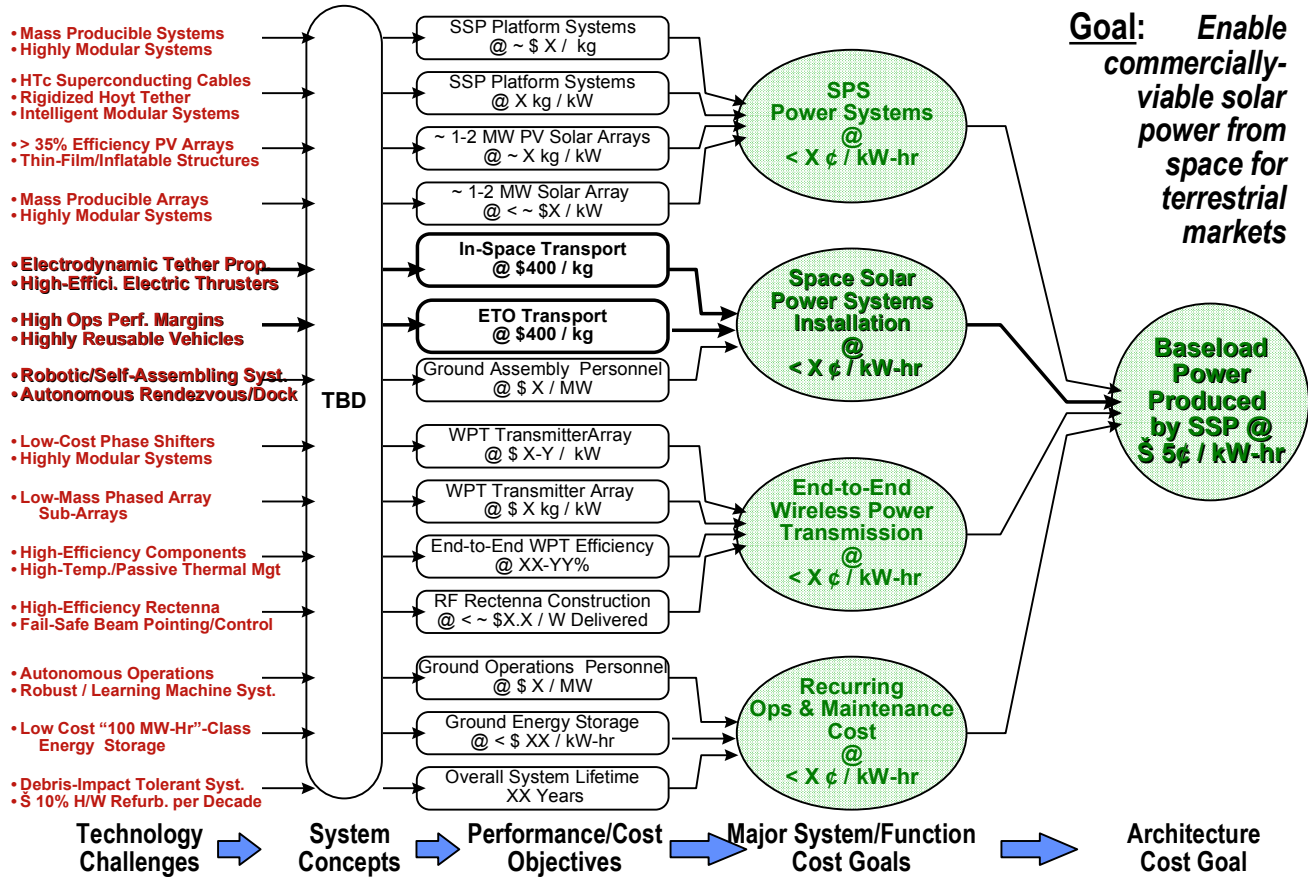


FIGURE 8—Overall SSP Technology Planning Scenario. Allocating affordability goals is key

SPACEPORT TECHNOLOGY ROADMAPPING—A PROTOTYPE PROCESS

As previously mentioned, knowledge of generic spaceport functions and spaceport performance parameters are central to benchmarking, analytical modeling, technology planning, and ultimately, spaceport architectural master planning (see Figure 7). The Spaceport Synergy Team, having in its possession a few prototype tools in many of the above areas, committed to explore and develop a prototype spaceport technology roadmap based on the transportation needs of the SSP Exploratory Research & Technology (SERT) program in 1999.

Spaceport Technology Planning Scenario

Government and industry decision-makers need planning scenarios anchored on the attributes desired for future space transportation. Safety and dependability of the systems is paramount. So is responsiveness for the payload customer (either

cargo or passenger) and flight rate for the investors of the flight vehicles and the spaceport.

A truly affordable system would be one that avoids periodic catastrophic failure, forgoes long maintenance downtimes, does not require large amounts of labor and infrastructure services, and achieves high degrees of flight availability.

Since the overall affordability objective of the SSP enterprise is to achieve 5¢ per kW-hr, goals for the space transportation component of the enterprise can be derived from various market and economic models. These models determined that the overall price per kilogram of delivered SSP hardware needs to be around \$800/kg, with \$400/kg allocated for earth-to-orbit (ETO) transportation and \$400/kg allocated for in-space transportation to geo-synchronous earth orbit (GEO). Figure 8 traces the technology approach for the SSP example case.¹¹

SERT/Vision Spaceport Strategic Spaceport Technology Approach — Level A

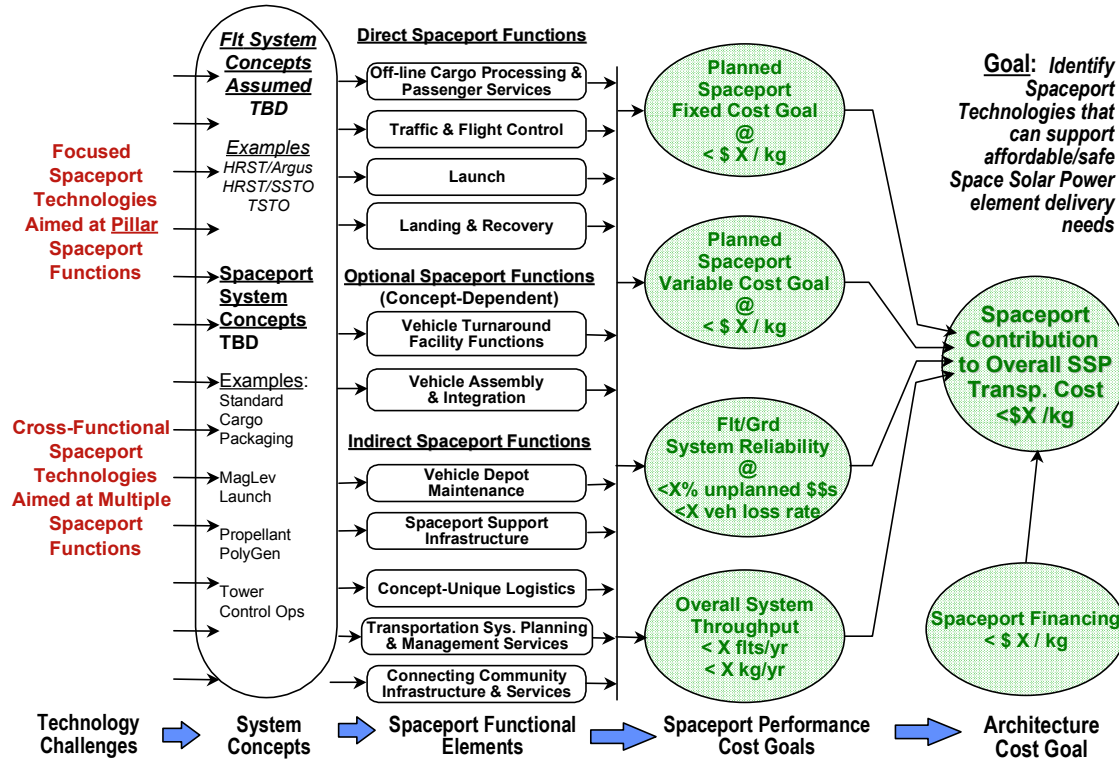


FIGURE 9—SERT/Spaceport Technology Planning Scenario. Again, allocating affordability goals is key.

Providing a specific transportation objective, like the Space Solar Power project in Figure 8, allows specific spaceport affordability objectives to be organized into the previously described spaceport functions (see Figure 9). Once flight system scenarios are defined, analysis of baseline spaceport performance can be determined from analytical spaceport models and easily traced to the overall transportation and enterprise goals and objectives. A proof-of-concept model was developed in 1998 during the SSP Concept Definition Study.¹² More in-depth models are in development by the Spaceport Synergy Team as part of the Vision Spaceport Project. Test runs with a “beta” version are planned for the current SERT activity in 1999. For the level of launch production needed by the SSP enterprise along with the price per kilogram delivered to orbit, specific flight system concepts can be chosen for a baseline. For instance, the Highly Reusable Space Transportation (HRST) study found that a rocket-based combined-cycle (RBCC) vehicle combined with MagLev ground launch assist had significant promise of achieving high degrees of affordability and high flight rates per vehicle.¹³

Spaceport Technology Prioritization Process The next step is to initiate a structured spaceport technology assessment process. This process involves several tasks, some of which can occur at the same time.

For instance, spaceport technology candidates can be collected into a database while work is initiated to determine customer needs for the spaceport. Simultaneously, a structured *house of quality* can be built which defines customers’ needs in terms of qualitative spaceport system attributes (e.g., affordability, responsiveness, dependability, safety, etc.).

These attributes, which relate to the benefit of a fielded spaceport system, are then assigned numerical weights primarily determined by the need for improvement in each attribute. Discriminating by need for improvement versus design importance is often easily missed, but essential strategy for tackling the problem of technology prioritization.

The next step requires assembling experienced spaceport technologists that can identify key

measurable design features that are associated with improving the qualitative attributes of a spaceport. In this prototype technology roadmapping exercise, daily flights from Earth that cumulatively delivers thousands of metric tons of space solar hardware per year—safely and without periodic loss of vehicle or cargo is the spaceport technology objective.

A basis is now formed for evaluating the operational benefit of proposed spaceport technologies (see ordinate in Figure 10). The foregoing attributes are time and budget independent. Still needing to be addressed are issues of research and technology (R&T), as well as the development and acquisition of the operational spaceport facilities and equipment. These costs, schedules and risks are the *programmatic factors* needed for construction of time-phased and budget-dependent roadmap scenarios. However, once these programmatic factors have been determined and weighted in priority by the decision-makers, a full prioritization framework will have been established (see abscissa in Figure 10).

Technology candidates can now be assessed and plotted for overall operational benefit and relative programmatic maturity for both government R&T investment and commercial financing and acquisition of spaceports. Two plots are constructed. One for operational benefit vs. the R&T programmatic factors for long-range technology planning (suitable for government investors), and another for operational benefit vs. acquisition programmatic factors (suitable for commercial spaceport planners, investors and financiers).

Having gone through this process, a narrowed candidate set of technologies can now be traded against baseline transportation system concepts in the context of the enterprise under study—i.e., space solar power.

Anchoring Technology Priorities with Spaceport System Concept Models Combinations of high-priority technology candidates can now be explored in a more quantitative environment with analytical models that project the life cycle consequences of specific design choices.

Spaceport Concept & Technology Strategic Prioritization

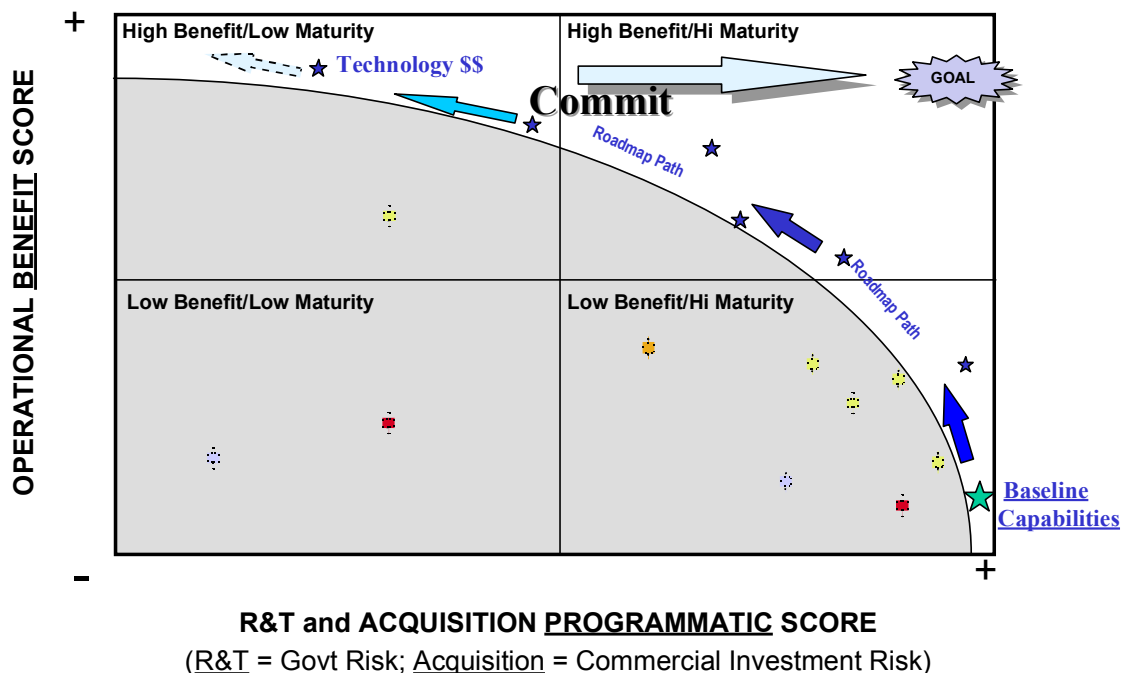


FIGURE 10—Technology Prioritization “Quad Chart”, a very useful spaceport technology planning tool

The cumulative effect of technology on specific spaceport elements of cost and throughput performance (e.g., kilograms per year per) are planned for the SERT activity by grouping previously identified technologies and running them against the analytical model to determine how well the group “closes the gap” in performance.

These outputs will anchor the technology priorities on (1) spaceport and flight system architectures, (2) enterprise goals, with SSP as the example case, and (3) transportation performance objectives.

Spaceport Technology Investment Plans

Through iterations of this process, groups of system concepts and technologies will emerge. Technology assessment “quad charts” capture the knowledge of spaceport technologists, and analytical models quantify their ideas and priorities. With these in hand, structured spaceport technology investment plans can be developed. The method described, with its various interim outputs, traces spaceport technologies and system concepts to overall objectives and goals. Further refinement of R&T costs and schedules would need to be accomplished and then worked into spaceport technology budgets.

Programmatic Sensitivities

A baseline can be formed from which accelerated or deferred roadmaps can be generated based on the programmatic environment. An accelerated roadmap would tend to delete long-lead and expensive technology, but would lose whatever benefit was associated with the technology. The tools would be in place to run such a scenario. Likewise, if a scenario was run which deferred implementation from the baseline, then there might be more time to mature certain technologies and evaluate their benefit. Again, the technology assessment and analytical models would be available to run this scenario.

The Roadmaps

This investment plan can be summarized in time-phased and budget-dependent scenarios and placed on schedule/milestone charts as “Spaceport Technology Roadmaps.

Finally, as the technology investment plans and budgets begin to come together and mature, large-scale spaceport architectural planning can begin.

Detailed facility master planning will be ready for commitment.

SUMMARY

A structured approach has been explored for developing strategic spaceport concepts and technologies. A prototype case study for space solar power technology deployment is providing a context for using tools and methods applicable to spaceport concept and technology development. The methods and tools employed are part of a larger Spaceport Technology Center initiative intended to provide a strategic, structured approach to improve the world’s space launch capabilities.

CONCLUSIONS

Analytical methods and tools used for spaceport architectural planning are in their early stages of research and development and will take years to properly validate. Tremendous strides are being made in developing models useful for space transportation concept exploration and early concept definition. As mentioned earlier, more detailed and thorough benchmarks of performance are needed for basic spaceport functions. Once detailed knowledge is captured in such models, standard and robust modeling techniques can be applied. At that point spaceport design and development will evolve from an art to a science.

Looking ahead, the Vision Spaceport Project is pursuing not only numerical analytical models, but also modeling technologies that anticipate the need for other advanced design capabilities. One area under focus is visualization of spaceport/flight system architectures whose elements are defined and characterized by a core analytical model. The Vision Spaceport Project Team has demonstrated proof-of-concept electronic visualization of spaceport architectures. NASA’s Ames Research Center is leading continued advancement of the visualization module with The University of Central Florida’s Institute for Simulation & Training (IST).

A more important interim step, however, needs to occur. Collaborative engineering design methods employed in a design environment where immediate consequences of space transportation design choices will expedite affordable, safe and productive space transportation.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the sponsorship of the Vision Spaceport Project partnership. Also, acknowledgment is made of Mr. John Mankins/ NASA Headquarters, for his support and guidance. In addition, the author would like to thank Mr. Joe Howell, NASA Marshall Space Flight Center and Mr. Russel Rhodes, NASA KSC. Finally, Mr. Edgar Zapata and his Vision Spaceport Task 8.0 Team is leading the tremendous work in this important subject.

ACRONYMS/ABBREVIATIONS

Arch.	Architecture
CCT	Command & Control Technologies
ETO	earth-to-orbit
Flt	flight
Flts/yr	flights per year
GEO	geosynchronous earth orbit
Grd	ground
H/W	hardware
HRST	Highly Reusable Space Transportation
IST	Institute for Simulation and Training
kg	kilogram
kg/yr	kilograms per year
KSC	John F. Kennedy Space Center
kW	kilowatt
kW-hr	kilowatt-hour
MagLev	magnetic levitation
MW	megawatt
MW-hr	megawatt-hour
NASA	National Aeronautics & Space Administration
Ops	operations
PV	photo-voltaic
QTSI	Quantum Technology Services, Inc.
R&T	research and technology
RBCC	rocket-based combined-cycle
RF	radio frequency
SAIC	Science Applications International Corporation
SERT	SSP Exploratory R&T
SPS	Solar Power Satellite
SSP	space solar power
SSTO	Single Stage-to-Orbit
STC	Spaceport Technology Center
STDI	Spaceport Technology Development Initiative
TBD	to be determined
Transp.	Transportation
TSTO	Two Stage-to-Orbit
USA	United States of America
veh	vehicle
vs.	versus
WPT	wireless power transmission

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